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Bycatch of crustacean and fish bottom trawl fisheries from southern Portugal (Algarve)

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SUMMARY: As part of two research projects for analysing bycatch and discards, we quantified catch composition, catch rates, bycatch and discards in two important commercial bottom trawl fisheries (crustacean and fish trawls) off the southern coast of Portugal (Algarve). Stratified sampling by onboard observers took place from February 1999 to March 2001 and data were collected from 165 tows during 52 fishing trips. Commercial target species included crustaceans: blue and red shrimp (*Aristeus antennatus*), deep-water rose shrimp (*Parapenaeus longirostris*), Norway lobster (*Nephrops norvegicus*); and fishes: seabreams (*Diplodus* spp. and *Pagellus* spp.), horse mackerels (*Trachurus* spp.) and European hake (*Merluccius merluccius*). The trawl fisheries are characterised by considerable amounts of bycatch: 59.5% and 80.4% of the overall total catch for crustacean and fish trawlers respectively. A total of 255 species were identified, which belonged to 15 classes of organisms (137 vertebrates, 112 invertebrates and 6 algae). Crustacean trawlers had higher bycatch biodiversity. Bony fish (45.6% and 37.8%) followed by crustaceans (14.6% and 11.5%) were the dominant bycatch components of both crustacean and fish trawlers respectively. The influence of a number of factors (e.g. depth, fishing gear, tow duration and season) on bycatch and discards is discussed.

Keywords: bycatch, trawl fisheries, fish, crustacean, Algarve, Portugal.

RESUMEN: CAPTURAS INCIDENTALES DE LAS PESQUERÍAS DE ARRASTRE DE FONDO DE CRUSTÁCEOS Y PECES AL SUR DE PORTUGAL (ALGARVE). – Se ha cuantificado la composición de las capturas, sus tasas, las capturas incidentales y los descartes de dos pesquerías industriales de arrastre de fondo dirigidas a crustáceos y peces del sur del Portugal (Algarve). Se realizó un muestreo estratificado mediante observadores a bordo desde febrero de 1999 hasta marzo de 2001, utilizándose los datos recogidos en 52 embarques y 165 lances. Las especies objetivos de la pesquería comercial fueron: la gamba roja (*Aristeus antennatus*), la gamba blanca (*Parapennaeus longirostris*), la cigala (*Nephrops norvegicus*), varias especies de espáridos de los géneros *Diplodus* y *Pagellus*, jureles (*Trachurus* spp.) y merluza (*Merluccius merluccius*). Estas pesquerías de arrastre de fondo se caracterizaron por la presencia de considerables cantidades de capturas incidentales, que variaron entre un 59.5 y un 80.4% del total de las capturas de crustáceos y peces, respectivamente. Se identificaron 255 especies pertenecientes a 15 clases de organismos (137 vertebrados, 112 invertebrados y 6 algas). Se observó que la mayor biodiversidad se produjo en los arrastreros dirigidos a la captura de crustáceos. El componente dominante de las capturas incidentales en los arrastreros dirigidos a crustáceos y peces fueron los teleósteos (45.6 y 37.8%, respectivamente), seguidos por los crustáceos (14.6 y 11.5%). Se discute la influencia de varios factores (i.e. la profundidad, el tipo de aparejo, la duración del lance o la estación del año) en las capturas incidentales y los descartes.

Palabras clave: capturas incidentales, pesquería de arrastre, peces, crustáceos, Algarve, Portugal.

INTRODUCTION

Although concern about bycatch in commercial and recreational fisheries can be found in the scientific literature from the mid-1970s, it became the most critical fisheries issue in the 1990s (e.g. Alverson *et al.*, 1994; Kennelly, 1995; Alverson and Hughes, 1996; Hall *et al.*, 2000). Given the overfished state of many of the worlds most important stocks (Pauly *et al.*, 2002), there has been great interest in documenting and finding solutions to the economic, political, and ecological implications of bycatch and discarding. The worldwide interest has given rise to a significant number of research papers, reviews and conferences (e.g. Saila, 1983; Alverson and Hughes, 1996; FAO, 1996; Hall, 1996, 1998; Zann, 2000; Sánchez *et al.*, 2004; and many others). Furthermore, there is growing international concern for the conservation of bycatch species (Nakano *et al.*, 1997). The first global estimate of bycatch was approximately 12 million tonnes (Mt), with 3 to 5 Mt a year for the shrimp trawl fisheries alone (Slavin, 1981; Saila, 1983). Later, Alverson *et al.* (1994) estimated an annual shrimp trawl bycatch of around 11.2 Mt worldwide and the global annual commercial fisheries bycatch was estimated to be an average 28.7 Mt per year (FAO, 1996).

Most marine fisheries are mixed fisheries directed at only a few commercial target species; however, a wide variety of bycatch species are captured along with the target species (FAO, 1996; Castriota *et al.*, 2001). Some of these species have economic value and can be retained and commercialised, while others are discarded overboard for a variety of reasons (Saila, 1983; Alverson *et al.*, 1994; Borges *et al.*, 2002; Stobutzki *et al.*, 2003).

Bycatch may include individuals of target species smaller than the legal minimum landing size, juveniles of commercial and/or recreational fisheries species, or individuals of threatened, endangered or protected species (Alverson *et al.*, 1994; Kenelly, 1995; Lewison *et al.*, 2004). Bycatch is by and large regarded as unavoidable, and it is not restricted to any particular gear type or any particular region of the world (Hall *et al.*, 2000). However, non-selective fishing gears such as trawls that catch almost everything in their path, are generally considered to have greater bycatch rates than more selective gears such as longlines and purse seines (FAO, 1996). Indeed, the issue of bycatch in bottom trawl fisheries is of particular concern in tropical shrimp fisheries, where the weight of bycatch can be 5 to 10 times greater than the weight of the target species and may account for 8 to 16 Mt per year as a whole (Andrew and Pepperell, 1992).

The bycatch of commercial fisheries worldwide is of great concern to fisheries managers and environmental and conservation groups as it contributes to biological overfishing and to changing the structure of marine communities and/or ecosystems, with serious implications for marine populations and the overall health and sustainability of ecosystems (Alverson *et al.*, 1994; FAO, 1997; Rebecca *et al.*, 2004).

The first step towards understanding and solving the bycatch problem is to identify and quantify bycatches (Alverson *et al.*, 1994; Kennelly, 1997; Ye *et al.*, 2000; Borges *et al.*, 2002). The most widely used approach for quantifying bycatches in commercial fisheries is to have onboard observers record the required data during normal fishing operations (Saila, 1983; Alverson *et al.*, 1994; Kennelly, 1995; FAO, 1996; Liggins *et al.*, 1996).

In Portugal, the "trawling" category includes fleet components that trawl for both crustaceans and fish (C.E.C., 1993a). The most important fraction of the Portuguese commercial trawl landings comes from the Algarve, with the crustacean trawl fishery constituting a very important part of the fishing fleet in the region (D.R., 1999; Pita *et al.*, 2001).

The present study is based on two research projects that analyse bycatch and discards and focus on the bottom (decapod crustaceans and fish) trawl fisheries of the southern Portuguese coast. We quantify here the composition and catch rates of the target and bycatch species of the fish and crustacean trawl fleets. While previous studies have focused on discards (Borges *et al.*, 1997, 2000, 2001, 2002; Monteiro *et al.*, 2001), this is the first study that specifically addresses the issue of bycatches of crustacean and fish trawlers. This research will increase our knowledge of the impacts of trawling on the area and will provide a useful point of departure and baseline for management and conservation and for present and future work in this field.

MATERIAL AND METHODS

The present study was carried out on commercial fishing vessels operating off the southern coast of Portugal (Algarve) (Fig. 1) from February 1999 to March 2001, during two projects on fisheries bycatch and discards. Sampling was stratified by bottom trawl type (crustacean trawlers and fish trawlers) and season (four) per year. Given the larger bycatch quantities and diversity of crustacean trawlers, the sampling effort was 4 or 5 fishing trips per season for crustacean trawlers compared to 3 fishing trips per season for fish trawlers. Data were collected by onboard observers following the direct collection method, which consists in observers onboard commercial boats asking the skippers to identify the target species at the beginning of each trip.

Onboard the trawlers, observers recorded all the information needed to characterise the fishing vessel, fishing gears and fishing trips (number and duration of trips and tows), catch quantities (total catch, target catch, retained catch, total bycatch, commercial bycatch and discarded bycatch), species composition, and geographical and bathymetric location of the fishing area using onboard electronics. Catch estimates depended on the amounts caught per tow: if large amounts were caught, the size of the catch was estimated by the skipper of the fishing vessel. In the case of small amounts, the total catch was obtained by summing the weight of each commercial (target and bycatch species) species sorted into baskets by the fishermen. Commercial target species as well as bycatch species were measured onboard, with cephalothorax length (mm) and total length (cm) recorded for crustaceans and fish respectively. All data was collected by individual tow per fishing trip and all tows were conducted in a manner that reflected normal commercial practice.

Sampling was concentrated on trawlers based in Portimão and Olhão (Fig. 1), which are the two main fishing ports in the Algarve. The entire Algarve was considered to be a single fishing ground (Borges *et al.*, 2000). Data on the technical characteristics of trawl vessels (year of construction, overall length (in meters), gross registered tonnage (GRT), and engine power in Horsepower, hp, and Kilowatts, kw) and on the number of trawl licences for 1999, 2000 and 2001, were obtained from official archives.

The crustacean trawl fisheries in the Algarve take place on the lower continental shelf and continental slope at depths from 150 m to 800 m, depending on target species (S.E.P., 1984). The most important crustacean trawl target species are the decapod crustaceans, such as blue and red shrimp (*Aristeus antennatus*), deep-water rose shrimp (*Parapenaeus longirostris*), and Norway lobster (*Nephrops norvegicus*). As of 22 November, 2000, the minimum legal mesh size was increased from 55mm to a range of 55 to 59 mm. The total catch of crustacean trawlers that use this mesh size range must consist of a minimum of 30% of target species and a maximum of 30% of bycatch species (fishes and cephalopods) (D.R., 2000).

Fish trawlers operate on the continental shelf and upper continental slope, mainly at depths between 100 and 200 m (Borges *et al.*, 2001; Erzini *et al.*,

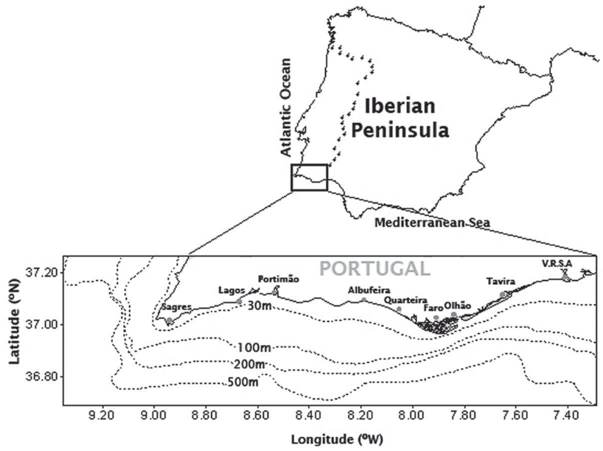

FIG. 1. – Algarve region, showing the main fishing ports in the region.

2002), and the most important target species are horse mackerel (*Trachurus* spp.), European hake (*Merluccius merluccius*) and sea breams (*Diplodus* spp. and *Pagellus* spp.). Since 2000, the minimum legal mesh size is in the range from 65 to 69 mm, and a minimum of 70% of the catch must consist of the target species. Trawlers using codend mesh sizes greater than 70 mm have no such restrictions regarding target species. However, the crustacean bycatch of fish trawlers must not exceed 20% of the total catch (D.R., 2000). Crustacean and fish trawlers constitute two different fleets with vessels that do not switch between fishing methods.

In this paper we use the following terms and definitions: *total catch* is the quantity of all species brought onboard; *target catch* is the fraction of the total catch which includes the species towards which the fishing effort is directed (target species); *retained (or landed) catch* is the part of the total catch that has economic value (i.e. the quantity of target and bycatch species that can be marketed); and *total bycatch* is the portion of the total catch which includes all the species caught accidentally (non-target species). Total bycatch may be retained if it has commercial value (commercial bycatch) and/or discarded at sea if it is not used for any purpose (discarded bycatch). In order to simplify, "*discarded bycatch*" will be referred to as "*discard(s)*" throughout this paper. It is also necessary to highlight that both the targeted and non-targeted species may be either marketable or discarded at sea.

The means and respective standard deviations of the different catch compositions were calculated according to trip and tow. In order to determine if there

TABLE 1. – Estimates of the total, target and retained catches, bycatch, commercial bycatch and discards, for the number of trips and fishing operations (tows) (* no trips due to fish trawlers strike; **no trips due to bad weather conditions; m=mean; s.d.=standard deviation).

Season	Métier	Boat (n)	Trips (n)	Tow (n)	Catch (kg) Total	Catch m/trip	Catch s.d.	Catch m/tow	Catch s.d.	Target Catch (kg) Total	Target m/trip	Target s.d.	Target m/tow	Target s.d.	Retained Catch (kg) Total	Retained m/trip	Retained s.d.	Retained m/tow	Retained s.d.
Winter 1998	Crustacean trawl	2	4	8	2160	540	88.48	270	101.98	1117	279	54.60	140	105.93	1368	342	58.37	171	118.36
	Fish trawl	2	3	19	27957	9319	1274.09	1471	2097.65	2835	945	56.07	149	167.11	7298	2433	36.49	384	333.64
Spring 1999	Crustacean trawl	2	4	9	1755	439	52.97	195	72.46	540	135	18.96	60	28.41	1166	291	30.85	130	51.09
	Fish trawl*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Summer 1999	Crustacean trawl	3	5	10	2330	466	64.48	233	75.58	1057	211	39.11	106	38.29	1332	266	32.68	133	35.48
	Fish trawl	3	3	18	8720	2907	85.18	484	435.22	2648	883	61.82	147	103.93	4327	1442	62.32	240	136.28
Autumn 1999	Crustacean trawl	2	3	5	1322	441	209.92	264	203.49	336	112	10.21	67	12.83	370	123	23.82	74	21.39
	Fish trawl	3	3	19	8065	2688	101.13	424	341.84	2186	729	19.81	115	141.43	4769	1590	33.73	251	201.99
Winter 1999	Crustacean trawl	3	3	6	1320	440	57.66	220	92.74	682	227	44.33	114	61.30	811	270	59.89	135	71.82
	Fish trawl	2	2	10	3540	1770	18.86	354	191.44	970	485	60.99	97	71.15	2059	1030	87.92	206	81.42
Spring 2000	Crustacean trawl	3	4	7	1485	371	113.07	212	109.69	559	140	34.82	80	35.45	940	235	95.53	134	78.77
	Fish trawl	2	3	12	2970	990	60.09	248	99.01	1347	449	62.23	112	78.80	2109	703	45.84	176	89.04
Summer 2000	Crustacean trawl	2	5	9	1115	223	61.02	124	70.70	370	74	18.35	41	19.92	517	103	26.13	57	26.32
	Fish trawl	2	3	15	4030	1343	219.95	269	331.90	847	282	28.80	56	58.48	1973	658	69.22	132	88.57
Autumn 2000	Crustacean trawl	2	3	8	700	233	60.24	88	70.46	316	105	20.34	40	28.39	385	128	22.12	48	30.81
	Fish trawl**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Winter 2000	Crustacean trawl	1	4	10	2800	700	55.28	280	58.69	1100	275	30.43	110	29.44	1141	285	28.80	114	29.15
	Fish trawl**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	Crustacean trawl	20	35	72	14987	428	100.47	208	83.01	6077	174	43.73	84	55.97	8029	229	57.30	112	67.49
	Fish trawl	14	17	93	55282	3252	708.50	594	1064.04	10833	637	55.06	116	118.84	22535	1326	101.41	242	207.80

Season	Métier	Boat (n)	Trips (n)	Tow (n)	Bycatch (kg) Total	Bycatch m/trip	Bycatch s.d.	Bycatch m/tow	Bycatch s.d.	Commercial Bycatch (kg) Total	Comm. m/trip	Comm. s.d.	Comm. m/tow	Comm. s.d.	Discards (kg) Total	Discards m/trip	Discards s.d.	Discards m/tow	Discards s.d.	Commercial bycatch (%)
Winter 1998	Crustacean trawl	2	4	8	1043	261	62.37	130	55.29	251	63	11.38	31	17.76	792	198	56.59	99	56.49	18.3
	Fish trawl	2	3	19	25122	8374	1262.60	1322	2047.60	4463	1488	47.77	235	277.93	20659	6886	1299.93	1087	2040.90	61.2
Spring 1999	Crustacean trawl	2	4	9	1216	304	37.39	135	47.54	627	157	18.02	70	29.01	590	147	31.07	66	34.09	53.7
	Fish trawl*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Summer 1999	Crustacean trawl	3	5	10	1273	255	61.54	127	75.40	275	55	13.28	28	21.48	998	200	55.57	100	69.26	20.6
	Fish trawl	3	3	18	6072	2024	146.13	337	427.81	1679	560	52.30	93	74.46	4393	1464	140.02	244	396.05	38.8
Autumn 1999	Crustacean trawl	2	3	5	986	329	212.00	197	203.82	34	11	14.00	7	11.01	952	317	220.16	190	209.67	9.2
	Fish trawl	3	3	19	5879	1960	86.93	309	276.22	2583	861	50.11	136	93.70	3296	1099	110.48	173	256.80	54.2
Winter 1999	Crustacean trawl	3	3	6	638	213	27.49	106	40.02	129	43	15.60	22	16.22	509	170	29.31	85	40.03	15.9
	Fish trawl	2	2	10	2570	1285	42.13	257	179.99	1089	545	26.93	109	42.62	1481	741	69.06	148	197.88	52.9
Spring 2000	Crustacean trawl	3	4	7	926	232	88.28	132	85.25	381	95	77.99	54	60.44	546	136	57.96	78	65.81	40.5
	Fish trawl	2	3	12	1623	541	6.92	135	63.89	688	229	16.34	57	31.48	935	312	28.25	78	69.74	33.8
Summer 2000	Crustacean trawl	2	5	9	745	149	54.51	83	60.92	147	29	9.39	16	9.89	598	120	48.33	66	53.93	28.4
	Fish trawl	2	3	15	3184	1061	192.98	212	281.81	1127	376	40.99	75	53.17	2057	686	162.04	137	269.27	57.1
Autumn 2000	Crustacean trawl	2	3	8	384	128	40.14	48	43.11	69	23	2.71	9	4.45	315	105	38.97	39	42.15	17.9
	Fish trawl**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Winter 2000	Crustacean trawl	1	4	10	1700	425	31.91	170	52.49	41	10	1.81	4	2.33	1659	415	32.96	166	52.50	3.6
	Fish trawl**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	Crustacean trawl	20	35	72	8911	255	78.91	124	83.01	1941	55	34.92	27	31.54	6958	199	77.69	97	82.54	24.2
	Fish trawl	14	17	93	44450	2615	685.76	478	1028.27	11653	685	70.55	125	148.85	32747	1926	652.35	352	996.40	51.8

are significant differences in the target, total bycatch, commercial bycatch and discard catches between seasons in each trawl type, non-parametric tests that employ the ranks of the measurements instead of using the actual (raw) data, had to be applied since sample sizes were different between the seasons in each year. The two-sample Mann-Whitney test (U) (Zar, 1996), that is analogous to the two-sample t-test, was applied to spring, summer and autumn in the case of crustacean trawls and to all seasons in the case of fish trawls. For testing differences among groups where k (samples) > 2, non-parametric analyses of variance were applied by the means of the Kruskal-Wallis test (H), often known as "analysis of variance by ranks" (Zar, 1996).

Species diversity for target, bycatch and discard species was calculated in relation to bottom trawl type. Size frequency distributions of the target species of the two types of trawl, as well as of the most important bycatch species captured by fish trawls for which there is legislation concerning legal minimum landing size (LMLS), were prepared. Legal minimum landing sizes for each species are reported following the Portuguese legislation published in the D.R. (2001).

RESULTS

Observers sampled 9 different trawlers of the 27 to 37 that were licensed in the Algarve from 1999 to 2001. Six crustacean trawlers were sampled, ranging in age from 7 to 44 years (mean=19.8) with total lengths ranging from 23 to 30 m (mean=25.8 m). The mean GRT was 144.9 ton (s.d.=29.26) and mean engine power was 441.3 kw (s.d.=80.63). The three fish trawlers that were sampled were older (mean=33.67 years) and slightly larger (mean=30.7 m) than crustacean trawlers. The mean GRT was 172.1 ton (s.d.=2.22) and their engine power mean was somewhat greater, with a mean of 504.7 kw (s.d.=72.17kw).

Crustacean trawlers fished at depths from 117 to 754 m (mean= 463.3 m; s.d.=150.0). Trip duration varied from 45.8 to 94.1 hours (mean=69.5 hours; s.d.= 16.876) and tow duration ranged from 2.25 to 10.22 hours (mean=5.78 h; s.d.=1.89). Fish trawlers normally fished at depths between 100 and 290 meters, but some hauls were as shallow as 41 m (mean= 105.3 m; s.d.=43.95). Fish trawler trip duration varied from 27.5 to 49 hours (mean=43.4 h; s.d.= 7.944) and tow duration ranged from 22.2 minutes to 2.85 hours (mean=1.45 h; s.d.=0.48).

The sampling effort, the quantities caught and retained and the target and bycatch catches according to year and season are shown in Table 1. A total of 52 fishing trips were made (35 in crustacean trawlers and 17 in fish trawlers), during which 72 crustacean trawl tows and 93 fish trawl tows were sampled, which totalled 165 fishing operations. There were less crustacean trawl fishing operations, with a maximum of 3 tows per trip (mean=2.06, s.d.=0.34) and 5 to 10 tows per season (mean=8.00, s.d.=1.73), compared with fish trawls that had a maximum of 8 tows per trip (mean=5.47, s.d.=0.93) and 10 to 19 tows per season (mean=15.50, s.d.=3.83).

From the overall catch composition shown in Figure 2, it can be seen that total bycatch exceeded target catch in both types of bottom trawl, even though it is much higher in fish (80.4% in kg) than in crustacean (59.5% in kg) trawls. Crustacean trawls capture larger amounts of the target species (over 40% in kg) than fish trawls (less than 20% in kg), while quantities of both commercial bycatch and discards are quite similar in the two types of bottom trawls.

During the study period, of the 3 crustacean trawl target species, deep-water rose shrimp accounted for the largest percentage (49.2% in kg) of the target catch, followed by blue and red shrimp (30.1% in kg). Norway lobster accounted for only 20.7% of the target catch in kg (Table 2). There are 14 crustacean trawl commercial bycatch species. We consider 9 of these to be the major bycatch species as they each ac-

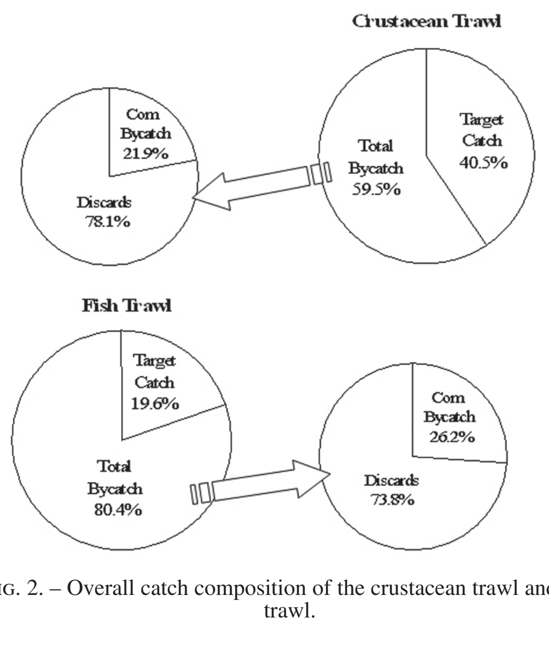

FIG. 2. – Overall catch composition of the crustacean trawl and fish trawl.

Table 2. – Target and commercial bycatch species caught by crustacean trawl off southern Portugal from 1999 to 2001(per tow) (s.d.=standard deviation).

Group / Species	Common name	Mean weight (kg)	(s.d.)	(%)
Target:				
Parapenaeus longirostris	Deep-water rose shrimp	60.7	57.59	49.2
Aristeus antennatus	Blue and red shrimp	37.2	32.72	30.1
Nephrops norvegicus	Norway lobster	25.5	32.13	20.7
Total				100.0
Commercial Bycatch:				
Chondrichthyes	Cartilaginous fish	14.3	13.65	21.5
Micromesistius poutassou	Blue whiting	9.7	3.21	14.5
Diverse		6.9	6.08	10.3
Lophius spp.	Angler	6.1	7.65	9.2
Merluccius merluccius	European hake	5.7	4.22	8.6
Phycis spp.	Forkbeard	4.5	2.87	6.7
Lepidopus caudatus	Silver scabbardfish	4.0	-	6.0
Conger conger	European conger	3.6	1.89	5.4
Cephalopoda	Cephalopodes	3.5	2.70	5.2
Maja squinado	Spiny spider crab	2.0	-	3.0
Trachurus spp.	Horse mackerel	2.0	-	3.0
Pagellus spp.	Seabream	2.0	1.41	3.0
Mullus spp.	Red mullet	1.8	1.66	2.6
Helicolenus dactylopterus	Blackbelly rosefish	0.8	0.35	1.1
Total				100.0

Table 3. – Target and commercial bycatch species caught by fish trawl off southern Portugal from 1999 to 2001(per tow) (s.d.=standard deviation).

Group / Species	Common name	Mean weight (kg)	(s.d.)	(%)
Target:				
Trachurus picturatus	Blue jack mackerel	142.5	143.96	30.2
Trachurus trachurus	Atlantic horse mackerel	132.3	96.49	28.0
Trachurus spp.	Horse mackerel	84.0	106.25	17.8
Merluccius merluccius	European hake	54.6	54.58	11.6
Pagellus spp.	Seabream	28.4	31.50	6.0
Pagellus acarne	Axillary seabream	15.0	-	3.2
Diplodus spp.	Seabream	10.3	10.94	2.2
Diplodus vulgaris	Common two-banded seabream	5.0	-	1.1
Total				100.0
Commercial Bycatch:				
Scomber japonicus	Chub mackerel	96.9	176.52	19.2
Sardina pilchardus	European pilchard	94.6	98.65	18.7
Scyliorhinus canicula	Small-spotted catshark	50.0	-	9.9
Parapenaeus longirostris	Deep-water rose shrimp	35.9	36.14	7.1
Scomber scombrus	Atlantic mackerel	34.4	38.83	6.8
Boops boops	Bogue	23.5	25.61	4.6
Chondrichthyes	Cartilaginous fish	19.7	16.75	3.9
Cephalopoda	Cephalopodes	19.2	12.02	3.8
Triglidae	Gurnard	14.8	3.02	2.9
Pagrus spp.	Seabream	14.2	5.08	2.8
Diverse		13.7	11.20	2.7
Pagrus pagrus	Common seabream	10.0	-	2.0
Sarpa salpa	Salema	10.0	-	2.0
Xiphias gladius	Swordfish	10.0	-	2.0
Octopus vulgaris	Common octopus	9.8	8.04	1.9
Spondyliosoma cantharus	Black seabream	8.4	5.03	1.7
Serranus cabrilla	Comber	8.0	-	1.6
Zeus faber	John dory	7.8	10.25	1.5
Conger conger	European conger	5.0	-	1.0
Mullus spp.	Red mullet	4.8	3.78	0.9
Pleuronectes platessa	European plaice	4.0	-	0.8
Helicolenus dactylopterus	Blackbelly rosefish	4.0	-	0.8
Solea spp.	Sole	2.0	1.41	0.4
Lophius spp.	Angler	2.0	-	0.4
Trisopterus luscus	Pouting	1.5	-	0.3
Mullus surmuletus	Stripe red mullet	1.0	-	0.2
Phycis spp.	Forkbeard	1.0	-	0.2
Total				100.0

counted for at least 5% of the bycatch (Table 2). Cartilaginous fishes accounted for the largest percentage in kg (21.5%) and blue whiting were the next most important commercial bycatch species (14.5%).

For the fish trawl, horse mackerel accounted for the highest percentage in kg (76%) of the target catch followed by European hake (11.6%) and seabreams (9.2%, for *Pagellus* spp. and 3.3% for *Diplodus* spp.) (Table 3). Fish trawl commercial bycatch species consisted of 27 species, of which 6 are considered to be the major bycatch species, as they each accounted for at least 5% of the bycatch in kg (Table 3). The most important fish trawl commercial bycatch species were chub mackerel (19.2% in kg) and European pilchard (18.8% in kg).

In crustacean trawls (Fig. 3) the target catches account, in kg, for approximately 30 to 40% in spring and autumn and 40 to 46% in summer and winter of the total catch. The target catches were largest in winter (46%) and smallest in autumn (32%). Total bycatch follows the same trends, with approximately 50% in winter and summer and 60 to 68% in spring and autumn, with a minimum of almost 54% in winter and maximum of almost 68% in autumn. The lowest values of commercial bycatch are found in autumn (7.5%) and winter (12.5%), and reach a maximum in spring (47%) but decrease to 20.9% in summer. There were more discards in crustacean trawls in autumn and winter (92.5% and 87.5% respectively) and less in summer, although discards still had relatively high values (79.1%). Only in spring did the amount of discards decrease, reaching a value of a little over 50%.

In all seasons, fish trawl total bycatch is greater than the target catch, especially in winter when it comprises almost 90% of the total catch (Fig. 4). In summer and autumn, both target catch and total bycatch are very similar, approximately 27% and 72% respectively. In spring the target catch reached its highest value (45.4%) which, in turn, decreased the total bycatch (54.6%).

Quantities of commercial bycatch (42% and 43.9%) and discards (58% and 56.1%) were quite similar in spring and autumn respectively. Discards were higher in winter (80%) and in summer (70%) and consequently lower in commercial bycatch (20% and 30.3% respectively).

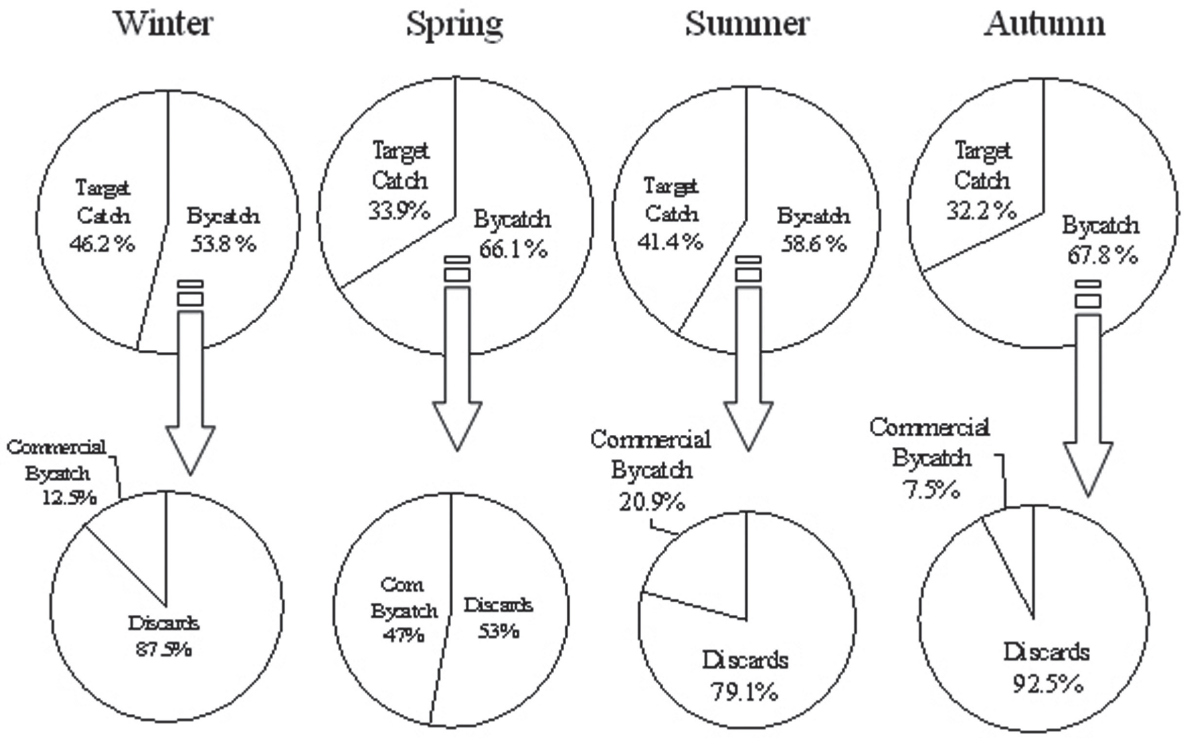

FIG. 3. – Overall catch composition of the crustacean trawl according to season.

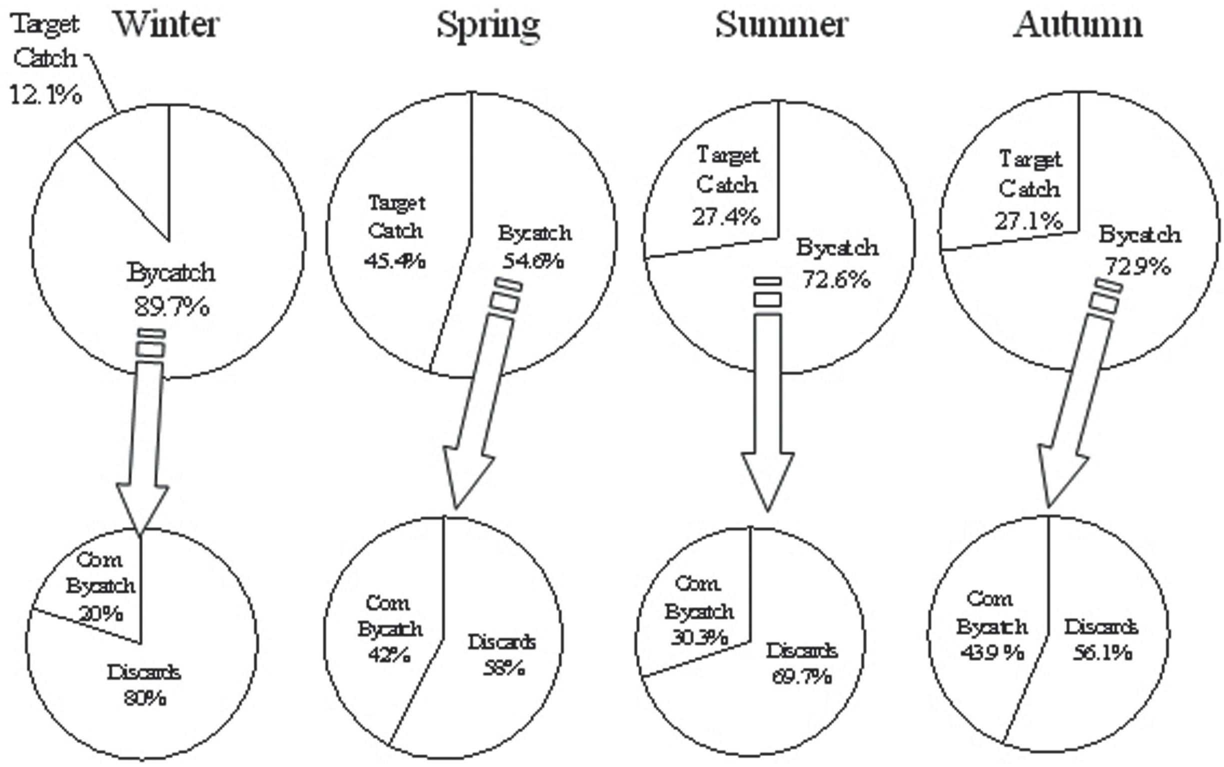

FIG. 4. – Overall catch composition of the fish trawl according to season.

Mann-Whitney tests applied to data from both types of bottom trawls showed significant differences at a significance level (α) of 0.05 only for the target catch in summer. No significant differences were found for the rest of the seasons and the rest of the catch components. The Kruskal-Wallis test ap-

TABLE 4 – Species composition, in number, of the bottom trawl catches off southern Portugal from1999 to 2001. CT, crustacean trawl; FT, fish trawl; C&FT, coincident in both trawls.

Class of organisms	Total Species				Target Species				Bycatch Species				Discarded Species			
	CT	FT	C&FT	Total	CT	FT	C&FT	Total	CT	FT	C&FT	Total	CT	FT	C&FT	Total
VERTEBRATES																
Chondrichthyes	18	7	4	21	0	0	0	0	18	7	4	21	13	4	2	15
Osteichthyes	94	65	43	116	0	6	0	6	94	59	43	110	54	23	17	60
INVERTEBRATES																
Malacostraca	33	18	15	36	3	0	0	3	30	18	15	33	28	14	9	33
Cephalopoda	17	18	13	22	0	0	0	0	17	18	13	22	9	9	6	12
Bivalvia	12	10	7	15	0	0	0	0	12	10	7	15	12	10	7	15
Gastropoda	11	15	7	19	0	0	0	0	11	15	7	19	11	15	7	19
Anthozoa	4	4	4	4	0	0	0	0	4	4	4	4	4	4	4	4
Polychaeta	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1
Ophiuroidea	2	3	2	3	0	0	0	0	2	3	2	3	2	3	2	3
Crinoidea	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1
Holothuroidea	1	2	1	2	0	0	0	0	1	2	1	2	1	2	1	2
Asteroidea	2	3	2	3	0	0	0	0	2	3	2	3	2	3	2	3
Echinoidea	5	5	4	6	0	0	0	0	5	5	4	6	5	5	4	6
ALGAE																
Chlorophyceae	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1	1
Phaeophyceae	4	3	2	5	0	0	0	0	4	3	2	5	4	3	2	5
Total (number)	206	156	107	255	3	6	0	9	203	150	107	246	148	98	66	180

plied to crustacean trawl catches also showed that in winter there are no significant differences in the overall catch compositions.

Of the total number of species (n=255) identified during the present study, 137 (53.7%) are fish, 36 (14.1%) are crustaceans, 56 (22%) are molluscs and 26 (10.2%) are invertebrate species from nine different taxonomic groups (Table 4). Of the total species caught, 80.8% came from crustacean trawlers and 61.2% from fish trawlers, with 42% common to both trawl types. Target species represent a small portion of the total number of species (3.5%), 3.8% and 1.5% respectively for fish and crustacean trawlers. The vast majority of the species are in fact bycatch species: 98.5% for crustacean trawlers, 96.2% for fish trawlers and 96.5% overall for the two types of trawlers. This means that only 27.1% (n=55) and 34.7% (n=52) of bycatch species captured respectively by crustacean and fish trawls have commercial value, and the rest are discarded.

Bottom trawl catches off southern Portugal appear to be very diverse (Fig. 5). Osteichthyes stands out as the dominant group of bycatch species, as it represents almost 46% and slightly less than 38% of crustacean and fish trawl catches respectively.

Size distributions of the target species caught by the two types of bottom trawlers are presented in Figures 6 to 10. Legal minimum landing sizes (LMLS) according to Portuguese legislation are rep-

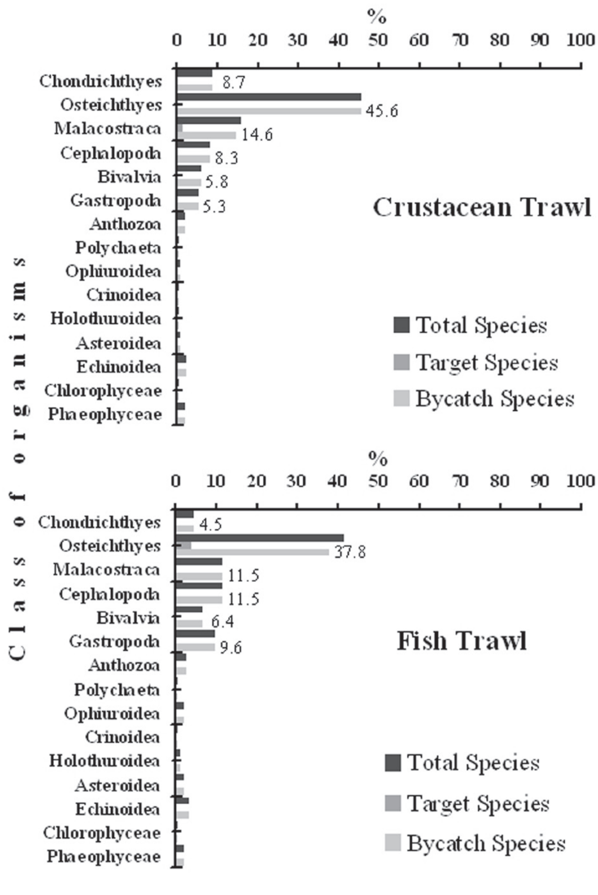

FIG. 5. – Contribution of each class of organisms to the biodiversity of the total, target and bycatch catches in the two types of trawlers. Each bar represents the percentage of the species in that class in relation to the total number of species present.

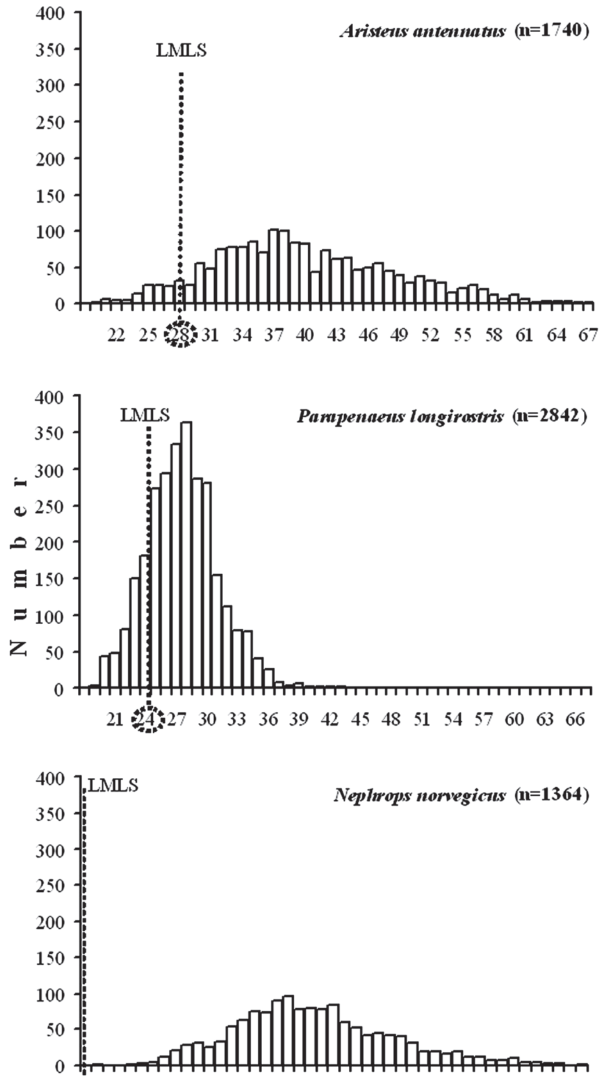

FIG. 6. – Length frequency distribution of the crustacean trawl target species (LMLS=Legal Minimum Landing Size).

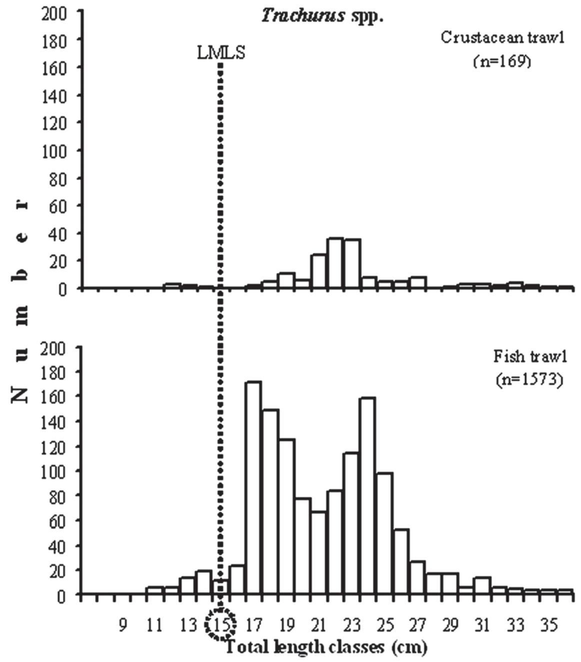

FIG. 7. – Length frequency distribution of the fish trawl target species *Trachurus* spp. (Horse mackerel) (LMLS=Legal Minimum Landing Size).

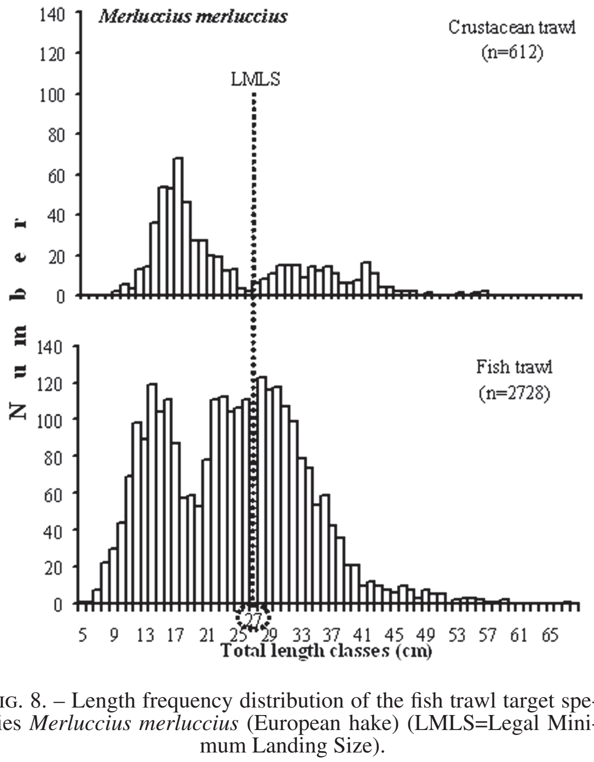

FIG. 8. – Length frequency distribution of the fish trawl target species *Merluccius merluccius* (European hake) (LMLS=Legal Minimum Landing Size).

resented by a dotted line and individuals under the LMLS were all discarded, mainly due to their small (illegal) size and/or their poor quality.

Size distributions of the three crustacean target species are represented in Figure 6. The majority of blue and red shrimp (92.3%) and deep-water rose shrimp (88.6%) were over the LMLS. All Norway lobster specimens sampled were greater than the LMLS legislated for this species.

Most of the horse mackerel individuals (96.8%) were above the LMLS in both types of trawl (96.4% in crustacean trawl and 96.8% in fish trawl) (Fig. 7). For European hake 68.1% and 57.7% of the individuals caught in crustacean and fish trawls respectively were smaller than the LMLS (Fig. 8). Only 40.4% were large enough to be landed.

Figure 9 shows the size composition of the seabream *Pagellus* spp., which is quite similar to that of the European hake, i.e., in the two types of bottom trawls only a few fish (19.3%) were greater than the LMLS of 18 cm (26.7% in crustacean trawls and

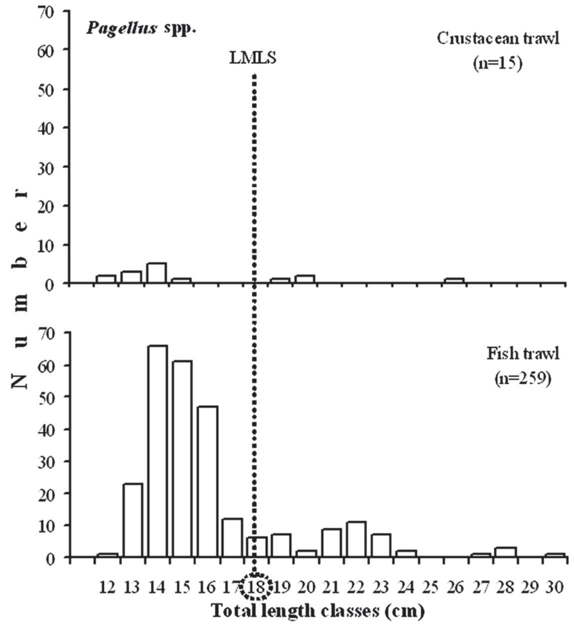

FIG. 9. – Length frequency distribution of the fish trawl target species *Pagellus* spp. (Seabream) (LMLS=Legal Minimum Landing Size).

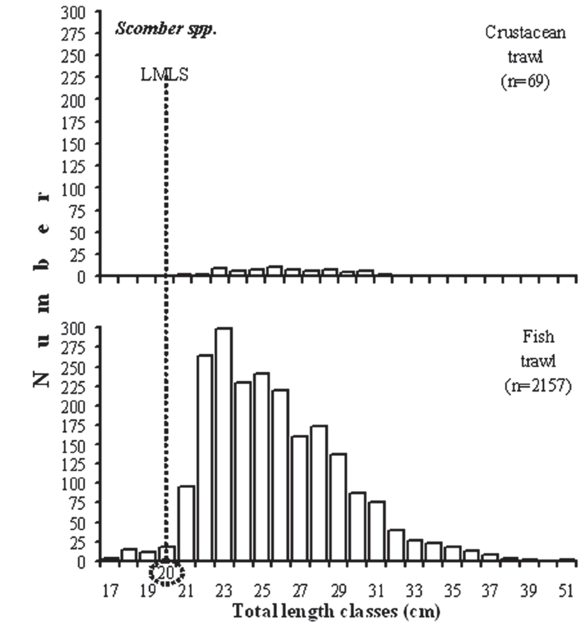

FIG. 11. – Length frequency distribution of the fish trawl target species *Scomber* spp. (Mackerel) (LMLS=Legal Minimum Landing Size).

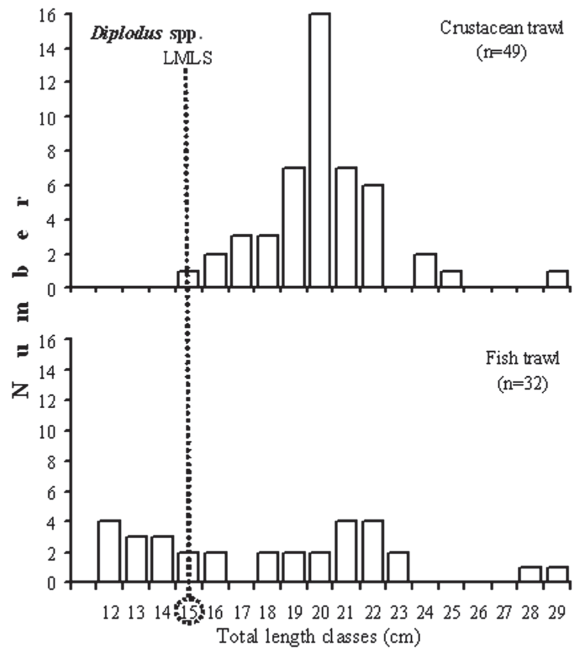

FIG. 10. – Length frequency distribution of the fish trawl target species *Diplodus* spp. (Seabream) (LMLS=Legal Minimum Landing Size).

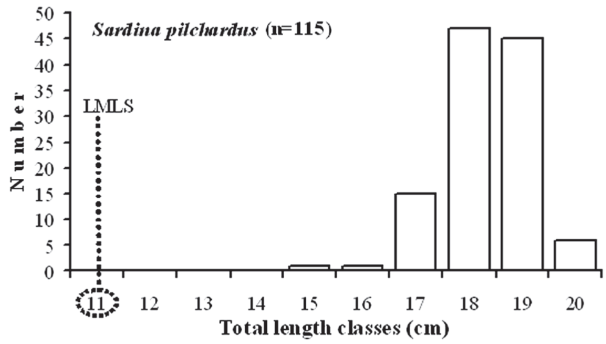

FIG. 12. – Length frequency distribution of the fish trawl target species *Sardina pilchardus* (European pilchard) (LMLS=Legal Minimum Landing Size).

18.9% in fish trawls) and were landed. For seabreams of the *Diplodus* genus caught both by fish and crustacean trawls the majority were of legal size, with 87.7% of the specimens greater than the LMLS.

The two most important bycatch species captured by fish trawls and for which a LMLS is applicable, are the horse mackerel species (*Scomber japonicus* and *Scomber scombrus*, grouped together as *Scomber* spp.) and the European pilchard, *Sardina pilchardus*. These species where chosen because their mean catch and mean catch rates were the highest (94.6 and 58.7 kg; 85.1 and 46.6 Kg/h respectively) of the commercialised bycatch species, and were in fact between those of the two most important fish trawl target species, the horse mackerel and European hake.

Length data and the respective LMLS for horse mackerel and European pilchard bycatch species are presented in Figures 11 and 12 respectively. Almost every horse mackerel specimen sampled (98.7%) was greater than the 20 cm LMLS. Those captured by crustacean trawls were all above the LMLS. All European pilchard specimens sampled were caught by fish trawlers and were greater than the LMLS.

DISCUSSION

Commercial bottom trawling (crustacean and fish trawls) is a very important activity in southern Portuguese waters, with approximately a third of the Portuguese trawl fleet based in the Algarve (D.R., 1999). Bottom trawling off the southern coast of Portugal generates significant amounts of bycatch, with the great majority (80.4% for fish trawlers and 60% for crustacean trawlers) of the total catch captured accidentally (total bycatch). Part of the total bycatch includes non-target species of high commercial value, but a considerable portion consists of non-marketable target species, represented by undersized or poor quality specimens, and bycatch species with low or no commercial value that are discarded at sea in relatively similar proportions in both trawl types (over 70%) (Monteiro *et al.*, 2001). The other fraction of the total catch is made up of target species, and is clearly higher in decapod crustacean trawls (40.5% compared to 20% in fish trawls).

Similar values of bycatch (about 80%) of the total catch were reported for the commercial bottom trawl fishery in the nearby western Mediterranean between 1995 and 1999 (Sartor *et al.*, 2003). The remaining fraction was also composed of target species, which represented a portion between 20% and 46% in all seasons. In contrast to our study, a significant portion of the bycatch consisted of commercial species, with higher values in summer.

Catch composition varies considerably according to a number of factors, including the nature of the fishery stock fished, the type of fishing gear used, gear selectivity, tow duration, target species and their price value, depth of capture, and the time of year (Oliver, 1993; Larson *et al.*, 1996; Merella *et al.*, 1998; Recasens *et al.*, 1998; García-Rodriguez and Esteban, 1999; Rochet *et al.*, 2002). The relatively non-selective nature of trawl nets in itself results in substantial quantities of bycatch (Monteiro *et al.*, 2001). In this study, only the summer target catches of both types of trawl differed significantly from those of the other seasons. This could be due to the fact that fishing effort was comparatively higher than during the other seasons, which leads to greater variability in the catches. Recasens *et al.* (1998) and García-Rodriguez and Esteban (1999), reported that when there are temporal variations in the catches it is important to consider the fluctuations in abundance and size range of the species studied.

Fishing trip duration is one of the most important factors influencing the proportion of the fish bycatch that is commercialised, and the quantity of bycatch landed is inversely related to trip duration (Clucas, 1997). Considering that fish trawler trip duration is significantly shorter (mean=43.4 h) than that of crustacean trawlers (mean=69.5 h), the higher values of commercial bycatch are understandable.

Sbrana *et al.* (2003) considers the variation in tow duration to be the main factor responsible for the seasonal variations in catches of the target species *A. antennatus* and *P. longirostris* in the western Mediterranean. According to Merella *et al.* (1998), tow duration is greatest when the yields are highest or when market prices reach their maximum values. This was observed for the target species *N. norvegicus* (Merella *et al.*, 1998), and for *A. antennatus* and *M. merluccius* (Oliver, 1993) for Mediterranean waters. In our study, an inverse relationship between tow duration and target species catch rates in most cases compounds the non-selectivity of the trawl nets, which leads to more bycatch being captured as well as more undersized individuals of the most valuable species. Seasonal variations in tow duration could be attributed to different species being targeted during certain periods as well as catches being made at different times.

Great diversity in bycatch species composition is a common phenomenon in trawl fisheries (Saila, 1983; Andrew and Pepperell, 1992 in Ye *et al.*, 2000; Stergiou *et al.*, 2003). This was also the case in this study, with a total of 255 species recorded, 246 (96.5%) of which contributed to the total bycatch. The differences between the two types of trawlers can be explained by the fact that crustacean trawlers exploit greater depths that are richer in terms of biodiversity. In addition, longer crustacean trawl tow duration may decrease the size selectivity of the trawl net as the catch accumulates in the codend (Murawski, 1996), thereby increasing the number of species and consequently the bycatch.

The dominant bycatch species captured by both types of trawlers, belong to the class Osteichthyes followed by molluscs (mainly cephalopods) and crustaceans. This is in agreement with the findings of Monteiro *et al.* (2001), also for Algarve coastal waters and in the Mediterranean (Sartor *et al.*, 2003).

Of the crustacean trawl target species, the largest catches are of the deep-water rose shrimp (*P. longirostris*) followed by blue and red shrimp (*A. antennatus*). The deep-water rose shrimp prefers sandy and/or muddy bottoms between 150 and 550 m, while *Aristeus antennatus* (blue and red shrimp) is more common in muddy grounds beyond 500 m and extending to 750 m (Cascalho, 1995; C.E.C., 1993b). The third target species, *Nephrops norvegicus* (Norway lobster), which has an irregular distribution between 170 and 700 m (Ribeiro-Cascalho and Arrobas, 1987; Cascalho, 1995) and is limited primarily by bottom topography and sediment type due to its burrowing behaviour (De Figueiredo and Viriato, 1992), represented only 20.7% of the target catches in the trawls that took place at an average depth of 463 m. Due to the low power of their engines, crustacean trawlers do not often fish at the depths where this species is most abundant (C.E.C. 1993b).

In the demersal fish trawl fishery, horse mackerels (*Trachurus spp.*) followed by European hake (*M. merluccius*) were the main target species with the highest mean catches (76% and 11.6% respectively). Figueiredo *et al.* (1994) also reported European hake as a commercial bycatch species in the crustacean trawl fishery, which accounted for 8.6% of the catch in mean weight. Higher values are referred to by Castriota *et al.* (2001) who found that European hake accounted for 28% for the commercial bycatch in the central Mediterranean and also by Monteiro *et al.* (2001), who reported that the European hake was the most landed bycatch species (91% of occurrence), with horse mackerel contributing only 3% to the commercial bycatch. The most important commercial bycatch species caught by fish trawls are *Scomber japonicus* and *Sardina pilchardus*. Whether these species are marketed or not depends on the total amount caught and on the prices at auction.

Other groups of organisms taken as bycatch can also have some commercial value in fish markets, as is the case of the Chondrichthyes and cephalopods. Chondrichthyes are important only as bycatch and marketable fresh only at large sizes and/or if the fish quota established for the crustacean trawlers allows them to be commercialised. In this study, this group is the dominant component of commercial bycatches in crustacean trawlers, and is composed of 18 species that represent 21.5% in mean weight, which is even greater than that of the target species *A. antennatus* (13%). In fish trawlers, it is the third most important commercial bycatch group, and represents 13.8% in mean weight (7 species caught), of which 9.9% alone is the species *Scyliorhinus canicula*. Some species of cephalopods have high commercial value while others can be commercialised but only if they are caught in significant quantities. Like cartilaginous fishes, the commercial bycatch group of cephalopods is more representative in crustacean trawlers (17 species caught and 5.2% in mean weight) than in fish trawlers (18 species caught and 3.8% in mean weight).

The existence of legal minimum landing sizes (LMLS) for most exploited species leads to proportions of both target and/or commercial bycatch species being discarded. Our results show that this is more significant for fish trawl catches. The clearest cases occur with the European hake and seabreams of the genus *Pagellus* spp. Moranta *et al.* (2000) suggests that this situation could be due, in part, to poor size selectivity in the codend for these species, with potentially important implications in terms of juvenile mortality.

In addition to the LMLS, there are other regulations for conserving fisheries and/or reducing the bycatch in Portugal. These include minimum legal mesh sizes for crustacean and fish trawl nets of 55 to 59 mm and 65 to 69 mm and/or≥70 mm respectively, minimum catch percentages of legal-sized target species of 30% for crustacean trawlers and 70% for fish trawlers, and maximum catch percentages of bycatch species of 30% for crustacean trawlers and 20% for fish trawlers. In this study, the quantities traditionally kept and distributed by fishermen for personal consumption were not taken into account, which probably justifies the higher percentages shown on some occasions.

Other alternatives for reducing bycatch of bottom trawls include research on the development and evaluation of the performance of more selective gear and fishing practices to permit juveniles to escape and to maximise the catch of target species. Research into reducing bycatch has been carried out in Portuguese waters since the 1990s. Experiments using square-mesh codend windows (Fonseca *et al.*, 1998; Campos *et al.*, 2002, 2003; Campos and Fonseca, 2004), diamond mesh codends (Campos *et al.*, 2002, 2003), separator panels (Campos and Fonseca, 2004), and modified Nordmøre grids (Fonseca *et al.*, 2005a,b) were, and still are, being carried out. These studies have demonstrated the varying effectiveness of such sorting devices in reducing the amount of bycatch(and discards) in trawl fisheries, and in allowing a high percentage of undersized specimens and non-commercial bycatch species to escape. However, the use of these devices has not been adopted by commercial fishermen due to the loss of part of the target catch and commercial bycatch species and the cost of implementing and operating such devices.

Knowing that the deep-sea fauna is quite diverse in the Algarve (Borges, 2007), and given the results of this particular study, it can be concluded that bycatch has important economic and ecological implications in this region. Removal of bycatch species by trawling can have a significant impact on marine trophic chains through predator-prey relationships and consequently on the whole ecosystem. This may be one of the reasons for the decrease in target species as well as overfishing.

Considering that both identification and quantification of bycatches are valuable pre-requisites for understanding the lesser known impacts of fishing and solving the problems, more attention should be paid to the bycatch issue in southern Portuguese waters. Efforts should be made to obtain information on the variables that influence the spatial and temporal distribution of bycatch, as well as on the biology of the species, including distribution, growth parameters, reproduction and feeding habits. This is essential for effectively managing this problem, as well as maintaining biodiversity and ecologic stability.

This study highlights the need for new and improved measures for mitigating the bycatch problem in Portuguese trawl fisheries. Although various bycatch reducing devices (BRDs) have been tested in Portuguese waters and size selectivity of both target and bycatch species has been studied (Campos et al. 2002, 2003; Campos and Fonseca 2003, 2004; Fonseca et al., 1998, 2005a,b), there has been little progress in terms of practical applications in the fishery. Indeed, as emphasised by Rawson (1997), the management of fisheries bycatch should consider all approaches for finding solutions that stabilise fish populations and the ecosystem consequences, while taking into account the human requirements for the marine resources.

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